

Attachment XI

Esters as Lubricating Oils

I. G. Leuna - Dr. H. Zorn

Paper Listing Properties of Esters

It has been known for some time that the lubricating properties of natural hydrocarbon lubricating oils are improved by the addition of natural fatty oils. In special cases, automobile and aircraft engines have been lubricated solely with natural fatty oils as, for example, castor oil. However, it has always appeared impossible permanently to obtain satisfactory lubrication of a given motor, since the fatty oils are not thermally stable to a sufficient extent. The reason for this lies in the thermal sensitivity of the secondary hydroxyl group of glycerol in acid medium. Since, on the other hand, fatty oils give appreciably more favorable behavior than do hydrocarbon oils in regard to lubricating property, that is, resistance to pressure and reduction of wear, it appeared necessary to synthesize esters which combined good lubricating properties with good thermal stability. The further demand of the automotive industry for good viscosity-temperature behavior (i.e., V.I. greater than 120) and good low-temperature behavior (i.e., pour point below -50°) was also involved here.

With the above background, the synthesis of esters and their engine testing were begun in 1938 by Dr. Zorn at Oppau together with Dr. Löwenberg at Leuna. This work was then continued at Leuna during 1939, 1940, and 1941. The esters prepared during this time and tested for numerous different applications as lubricants are described in the following table. A critical consideration of this material from the standpoint of relation between chemical constitution and lubricating properties is given in the second part of this report. At first, Dr. Löwenberg and Fräulein Dr. Rössig were involved in the preparation, development, and testing of ester lubricating oils; later on, Dr. Metzger and Dr. Gänicke participated.

Table 1

Run No.	Date of Preparation	Ester from Ethylene Glycol and:	Specific Gravity, at 20°C	Viscosity				m	V. I.	Four Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
150	4/22/39	Top cut of fatty acid C ₅ -C ₇	0.957	cs. 6.00 E 1.479	3.81 1.290	—	—	3.478	—	-50	146
291	10/11/39	1 part top cut of fatty acid C ₅ -C ₇ 1 part top cut of fatty acid C ₇ -C ₉	0.959	cs. 8.04 E 1.655	4.95 1.389	—	—	3.422	—	-31	
149	4/22/39	Top cut of fatty acid C ₇ -C ₁₁	0.945	cs. 8.325 E 1.680	5.08 1.400	—	—	3.470	—	-31	166
269	10/4/39	IS 140-E	0.946	cs. 7.35 E 1.595	4.29 1.332	—	—	3.624	—	-74	141
80	1/4/39	IS 200-250	0.938	cs. 10.4 E 1.868	5.45 1.474	—	—	3.713	—	-77	160
85	1/10/39	1 part IS 140-250 1.3 parts IS 200-250	0.944	cs. 11.8 E 2.00	6.375 1.511	—	—	3.645	—	-76	148
92	1/14/39	IS 200-250 + 10% higher fatty acids	0.937	cs. 22.6 E 3.17	11.7 1.991	—	—	3.673	144	-34	178

Table 2

Run No.	Date of Preparation	Ester from Tetra-methylene Glycol and:	Specific Gravity at 20°C	Viscosity			m	V.I.	Pour Point, °C	Flash Point, °C
				Unit 20°C	38°C	50°C				
146	4/19/39	Top cut of -fatty acid C ₅ -C ₇	0.950	cs. °E 7.64 1.620	4.82 1.387	—	3.348	—	163	
227	8/7/39	1 part top cut of fatty acid C ₅ -C ₇ 1 part top cut of fatty acid C ₇ -C ₉	0.938	cs. °E 9.90 1.822	5.79 1.46	—	3.377	—	169	
437	7/25/40	n-C ₈ acid	0.947	cs. °E 7.24 1.588	4.54 1.354	—	3.443	—	180	
266	9/22/39	Oil acid	0.936	cs. °E 36.7 12.74	41.66 5.55	—	3.412	129	277	
235	8/15/39	IS C ₆ -C ₇	0.935	cs. °E 8.34 1.681	4.98 1.391	—	3.415	—	160	
366	3/15/40	i-C ₈ acid	0.936	cs. °E 12.8 2.10	6.89 1.555	—	3.857	—	200	
236	8/15/39	IS 140-250	0.936	cs. °E 11.4 1.962	6.29 1.503	—	3.689	—	168	
101	2/2/39	1 part IS 140-250 1.5 parts IS 200-250	0.931	cs. °E 15.3 2.35	8.19 1.668	—	3.460	192	180	
264	9/22/39	IS 140-250 +5% oil acid	0.935	cs. °E 11.65 1.987	7.02 1.566	—	3.370	—	162	

Table 2-A

Run No.	Date of Preparation	Ester from Ethylene Glycol and:	Specific Gravity at 20°C	Viscosity				V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C			
150	4/22/39	Top cut of fatty acid C ₅ -C ₇	0.957	cs. °E 6.00 1.479	3.81 1.290	—	—	3.478	-50	146
291	10/11/39	1 part top cut of fatty acid C ₅ -C ₇ 1 part top cut of fatty acid C ₇ -C ₉	0.959	cs. °E 8.04 1.655	4.95 1.389	—	—	3.422	-31	172
149	4/22/39	Top part of fatty acid C ₇ -C ₁₁	0.945	cs. °E 8.325 1.680	5.08 1.400	—	—	3.470	-31	156
269	10/4/39	IS 140 - E	0.946	cs. °E 7.35 1.595	4.29 1.332	—	—	3.624	-74	141
80	1/4/39	IS 200-250	0.938	cs. °E 10.4 1.868	5.95 1.474	—	—	3.713	-77	160
85	1/10/39	1 part IS 140-250 1.3 parts IS 200-250	0.944	cs. °E 11.8 2.00	6.375 1.511	—	—	3.645	-76	148
92	1/14/39	IS 200-250 + 10% higher fatty acids	0.957	cs. °E 22.6 3.17	11.7 1.991	—	—	3.673	-34	178

Table 3

Run No.	Date of Preparation	Ester from Tetra-methylene glycol and:	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
265	9/22/39	LS 140-250 + 10% oil acid	0.934	cs. °E 12.7 2.09	7.18 1.530	— —	2.32 1.152	3.359	—	-71	184
171	5/13/39	LS 180-250 + 5% top cut of fatty acid C ₉ -C ₁₁	0.932	cs. °E 20.0 2.87	10.4 1.863	— —	2.80 1.198	3.541	170	-71	176
268	10/4/39	LS 200-250	0.930	cs. °E 14.8 2.59	11.8 3.00	— —	2.94 1.211	3.644	149	-70	208
371	4/3/40	C ₂ H ₉ - C - CH ₃ - COOH	1.020	cs. °E 14.8 2.50	7.81 1.535	— —	2.80 1.150	3.594	—	-10 (12)	—
645	4/7/41	Naphthenic acid	1.003	cs. °E 233.3 36.7	74.1 9.77	40.9 5.45	8.21 1.670	3.765	81	-40	346

Table 3A

Run No.	Date of Preparation	Ester from 1 Mole Adipol or Methyladipol and 2 Moles:	Specific Gravity, at 20°C	Unit	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C
					20°C	38°C	50°C	99°C				
838	9/12/41	<u>Adipol</u> IS C ₆ -C ₇	0.923	cs. °E	10.9 1.915	6.50 1.521	4.90 1.384	2.14 1.133	3.415	—	< -70 (-35)	180
813	9/2/41	i C ₈ - acid	0.920	cs. °E	16.6 2.49	8.675 1.711	5.18 1.494	2.37 1.157	3.726	—	< -72 (-50)	202
812	9/3/41	IS 200-250	0.925	cs. °E	23.53 3.28	12.2 2.04	8.50 1.704	3.20 1.235	3.437	178	-70	206
749	8/5/41	<u>Methyladipol</u> n C ₈ - acid	0.916	cs. °E	15.4 2.36	8.675 1.729	6.53 1.524	2.71 1.190	3.305	214	-23 (-16)	210
839	9/12/41	IS C ₆ -C ₇	0.923	cs. °E	12.3 2.05	7.15 1.577	5.31 1.420	2.25 1.145	3.452	—	< -70 (-35)	187
692	6/23/41	i C ₈ - acid	0.915	cs. °E	18.2 2.67	9.20 1.758	6.50 1.521	2.48 1.167	3.596	—	< -70 (-20)	202

Table 4

Run No.	Date of Preparation	Ester of Dimethylolpropane and:	Specific Gravity, at 20°C	Viscosity				V. I.	Pour Point, °C	Flash Point, °C		
				Unit	20°C	38°C	50°C				99°C	
543	1/5/41	Higher fatty acids	---	cs. 110 °E 14.48	49.5 6.56	---	---	8.14 1.664	3.215	137	10	272

Table 5

Run No.	Date of Preparation	Ester of Dimethylolpentane or Dimethylolhexane and:	Specific Gravity, at 20°C	Viscosity			m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C				
253	9/12/39	IS 140-250	0.929	cs.	17.6	8.83	—	—	2.51	167
				°E	2.60	1.725	—	—	1.151	
143	6/15/39	IS 180-200	0.925	cs.	27.4	12.2	—	82	2.72	163
				°E	3.75	2.04	—	—	1.191	
127	3/25/39	IS 200-250	0.921	cs.	44.4	19.9	—	103	3.78	188
				°E	5.89	2.86	—	—	1.287	
148	4/21/39	IS 140-250 + 20% top cut of fatty acid C ₅ -C ₆	0.928	cs.	17.5	8.90	—	—	2.36	151
				°E	2.59	1.731	—	—	1.156	
128	3/25/39	IS 200-250 + 5% higher fatty acids	0.918	cs.	55.1	22.7	—	125	4.36	188
				°E	7.29	3.18	—	—	1.338	

Table 6

Run No.	Date of Preparation	Ester of Dimethylolpentane or Dimethylolhexane and:	Specific Gravity, at 20°C	Viscosity				V.I.	Pour Point, °C	Flash Point, °C		
				Unit	20°C	38°C	50°C				99°C	
142	3/15/39	Dimethylolhexane IS 180-200	0.922	cs. °E 25.6 3.53	12.4 2.06	--	--	2.85 1.203	3.849	97	-65	165
147	4/21/39	IS 140-250 + 20% top cut fatty acids C ₅ -C ₆	0.928	cs. °E 16.5 2.48	8.57 1.702	--	--	2.80 1.150	3.808	--	-75	156
38	10/8/38	IS 200-250	0.919	cs. °E 36.06 4.83	15.9 2.42	--	--	3.47 1.26	3.699	125	-55	175
131	3/25/39	IS 200-250 + 15% higher fatty acids	0.913	cs. °E 48.8 6.47	21.66 3.06	--	--	4.16 1.521	3.709	118	-15	176
161	5/3/39	IS 200-250 + 20% higher fatty acids	0.917	cs. °E 49.9 6.51	22.1 3.11	--	--	4.33 1.535	3.628	129	-9	179
133	4/4/39	IS 200-250 + 25% higher fatty acids	0.914	cs. °E 53.1 7.03	23.0 3.22	--	--	4.46 1.347	3.611	131	-4	186

Table 7

Run No.	Date of Preparation	Ester of Dimethylolhexane or Dimethylol H S and:	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
210	6/20/39	Dimethylol H S 2 parts top cut of fatty acids C5-C6 3 parts top cut of fatty acids C7-C9	0.925	cs. °E	15.6 2.38	8.41 1.688	— —	2.40 1.160	—	-76	174
167	5/11/39	Top cut of fatty acids C5-C6 + 20% top cut of fatty acids C7-C11	0.932	cs. °E	14.5 2.27	7.92 1.645	— —	2.23 1.143	—	-78	159
207	6/20/39	Top cut of fatty acids C5-C6 + 30% top cut of fatty acids C7-C11	0.930	cs. °E	13.6 2.18	7.35 1.595	— —	2.07 1.136	—	-76	120
179	5/23/39	LS 165-250	0.923	cs. °E	27.5 3.76	13.4 2.16	— —	2.91 1.208	82	-60	158
155	4/28/39	LS 190-250	0.921	cs. °E	36.6 4.90	16.2 2.45	— —	3.29 1.243	95	-57	159
158	4/28/39	LS 140-250 + 5% top cut of fatty acids C5-C6	0.927	cs. °E	17.6 2.60	9.06 1.746	— —	2.35 1.153	—	-70	159

Table 7A

Run No.	Date of Preparation	Ester of Dimethylolhexane or Dimethylol H S and:	Specific Gravity, at 20°C	Viscosity					m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20° C	38° C	50° C	99° C				
178	5/23/39	IS 140-250 + 10% top cut of fatty acids C7-C11	0.925	cs. °E 17.6 2.60	8.90 1.731	—	—	2.31 1.151	3.878	—	-69	149
164	5/8/39	IS 165-250 + 15% lauric acid	0.922	cs. °E 32.8 4.42	14.9 2.31	—	—	3.14 1.230	3.764	98	-58	164
157	4/28/39	IS 180-250 + 15% top cut of fatty acids C5-C6	0.920	cs. °E 35.0 4.70	15.6 2.38	—	—	3.12 1.228	4.001	75	-58	169

Table 8

Run No.	Date of Preparation	Ester of 1 Mole Trimethylol-ethane and 3 Moles:	Specific Gravity, at 20°C	Viscosity				m.	V.I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
163	5/8/39	Top cut of fatty acids C ₉ -C ₁₁	0.917	cs. °E 68.2 9.0	31.3 4.23	--	5.51 1.437	3.533	134	-23	205
433	7/17/40	Higher fatty acids C ₁₀ -C ₁₆	0.920	cs. °E --	110.6 14.58	--	14.9 2.31	3.002	132	+6 (+10)	300
533	12/22/40	1 Mole higher fatty acids C ₁₀ -C ₁₆	0.948	cs. °E 585 77	191.7 25.23	--	15.3 2.35	3.564	86	+11	225
434	8/12/40	50 parts higher fatty acids 50 parts oil acids	0.924	cs. °E 205 27.0	84.2 11.09	--	12.2 2.04	3.066	135	-9 (+5)	290
216	6/30/39	Oil acids	0.915	cs. °E 113.3 14.91	52.4 6.94	--	9.90 1.822	2.886	154	-51 (-21)	309

Table 8A

Run No.	Date of Preparation	Ester from 1 Mole Trimethylol-ethane and 3 Moles:	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
600	3/24/41	Formic acid	1.224	cs. °E 22.3 3.14	10.0 1.851	6.62 1.532	2.52 1.171	4.609	114	-58	172
1	10/13/37	Acetic acid	1.112	cs. °E 32.3 4.36	12.4 2.06	7.63 1.619	2.26 1.146	5.091	--	-49	162
590	3/11/41	Top cut of fatty acid C ₅	0.990	cs. °E 20.3 2.90	10.8 1.905	--	2.72 1.191	3.722	139	<-72	205
584	3/7/41	Top cut of fatty acid C ₇	0.958	cs. °E 35.5 4.50	15.9 2.42	10.9 1.913	3.69 1.279	3.507	157	-70	241
202	6/20/39	2 parts top cut of fatty acids C ₅ -C ₆ 3 parts top cut of fatty acids C ₇ -C ₉	0.958	cs. °E 34.1 4.61	16.2 2.45	--	3.61 1.272	3.611	143	-67	184
272	10/11/39	2 parts top cut of fatty acids C ₅ -C ₇ 3 parts top cut of fatty acids C ₇ -C ₉	0.965	cs. °E 34.0 4.56	16.5 2.48	--	3.84 1.292	3.457	160	-62	227
62	11/18/38	Top cut of fatty acid C ₉	0.950	cs. °E 51.9 6.87	23.5 3.27	--	4.78 1.374	3.451	146	-46	206

Table 8B

Run No.	Date of Preparation	Ester from 1 Mole Trimethylol- ethane and 3 Moles:	Specific Gravity, at 20°C	Viscosity				m	V.I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
10	8/24/38	1S C ₆	0.978	cs. °F	30.2 4.09	14.8 2.3	—	3.21 1.236	114	-66	178
501	10/29/40	2 Moles 1S C ₆	0.991	cs. °F	61.6 8.13	23.4 3.26	14.4 2.26	3.82 1.291	52	-57	
6	6/27/38	1S C ₆ -C ₇	0.960	cs. °F	57.7 5.04	16.2 2.45	10.6 1.887	3.37 1.251	109	-59	205
599	3/16/41	2 Moles 1S C ₆ -C ₇	0.972	cs. °F	71.5 9.43	29.1 3.95	17.9 2.53	4.52 1.352	73	-50	188
558	12/21/40	1 Mole 1S C ₆ -C ₇	0.990	cs. °F	115 15.14	37.8 5.05	—	4.44 1.345	-27	-44	194
386	3/21/40	1-C ₈ acid 2 Ethyl-n-hexanoic acid	0.948	cs. °F	49.3 6.54	20.9 2.97	—	3.84 1.292	92	-63	210
387	3/28/40	1 part i-C ₈ acid 2 parts oil acid	0.924	cs. °F	121 15.93	53.7 7.10	—	9.31 1.768	146	-59 (-10)	300
846	9/23/41	1S 140-180	0.964	cs. °F	40.0 5.33	17.9 2.63	11.7 1.991	3.53 1.265	99	-60	204
170	12/5/39	1S 140-250	0.965	cs. °F	61.2 8.08	27.8 3.80	—	4.38 1.340	71	-49	190
165	5/8/39	1S 165-250	0.960	cs. °F	89.80 11.83	33.1 4.45	—	4.50 1.394	73	-48	199

Table 8C

Run No.	Date of Preparation	Ester from 1 Mole Trimethylolmethane and 3 Moles:	Specific Gravity, at 20°C	Viscosity			m	V. I.	Pour Point, °C	Flash Point, °C	
				Unit	20°C	38°C					50°C
141	4/15/39	1S 180-200	0.950	cs. °E	76.5 10.08	31.2 4.22	--	4.54 1.354	56	-54	198
155	4/27/39	1S 180-250	0.954	cs. °E	110.7 14.49	39.0 5.21	22.3 3.13	5.37 1.425	71	-49	215
140	4/13/39	1S 200-250	0.949	cs. °E	123 16.19	42.5 5.65	--	5.57 1.442	65	-48	209
572	2/14/41	2 Moles 1S 200-250	0.952	cs. °E	193 25.40	59.5 7.86	32.4 4.37	6.57 1.528	49	-44	208
589	3/10/41	1 Mole 1S 200-250	0.982	cs. °E	427 56.2	105 13.83	--	7.80 1.634	20	-33	198

Table 8D

Run No.	Date of Preparation	Ester from 1 Mole Trimethylolmethane and 3 Moles:	Specific Gravity, at 20°C	Viscosity				m	V.I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
83	1/5/39	1 part IS 140-250)	0.958	cs.	116	43.2	—	6.20	99	-27	195
		1.3 parts IS 200-250) + 10% higher fatty acids)									
102	2/2/39	1 part IS 140-180)	0.952	cs.	135	46.4	—	6.32	94	-9	196
		1.3 parts IS 200-250) + 15% higher fatty acids)									

Table 8E

Run No.	Date of Preparation	Ester from 1 Mole Trimethylol- ethane and 3 Moles:	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
108	3/1/39	1 part IS 140-250 1.3 parts IS 200-250 + 20% higher fatty acids	0.952	cs. °E 135 17.77	46.4 6.16	—	—	3.747	94	-9	196
78	12/24/39	1 part IS 140-250 1.3 parts IS 200-250 + 10% stearic acid	0.956	cs. °E 103 13.55	37.5 5.01	—	—	3.703	102	-15	205
180	5/23/39	IS 165-250 + 5% higher fatty acids	0.958	cs. °E 91.9 12.10	55.0 4.70	—	—	3.811	79	-35	190
415	6/25/40	IS 165-250 + 7.5% higher fatty acids	0.952	cs. °E 75.5 9.95	30.4 4.12	—	—	3.712	110	-48	235
181	5/23/39	IS 165-250 + 10% higher fatty acids	0.953	cs. °E 101.0 13.5	37.0 4.95	—	—	3.840	86	-29	195
201	6/19/39	IS 165-250 + 25% lauric acid	0.954	cs. °E 95.6 12.59	36.4 4.87	—	—	3.856	82	-53	192
200	6/18/39	IS 165-250 + 50% lauric acid	0.946	cs. °E 90.8 11.96	35.2 4.72	—	—	3.732	101	-23	192
426	7/12/40	IS 200-250 + 5% higher fatty acids	0.947	cs. °E 144.7 19.04	50.4 6.67	—	—	3.809	82	-45	249
413	6/23/40	IS 200-250 + 7.5% higher fatty acids	0.946	cs. °E 128 16.85	47.0 6.23	—	—	3.692	99	-38	250
292	11/6/39	IS 200-250 + 10% higher fatty acids	0.947	cs. °E 142 18.69	49.0 6.50	—	—	3.694	101	-38	247

Table 8F

Run No.	Date of Preparation	Ester from 1 Mole Trimethylolmethane and 3 Moles:	Specific Gravity at 20°C	Viscosity				m	V.I.	Pour Point, °C	Flash Point, °C	
				Unit	20°C	38°C	50°C					99°C
124	3/20/39	1S 200-250 + 15% higher fatty acids	0.946	cs. °E	168 22.11	56.7 7.5	— —	6.84 1.550	3.861	75	-7	185
445	8/16/40	1S 200-250 + 50% higher fatty acids	0.940	cs. °E	175.1 23.05	67.1 8.85	— —	9.05 1.746	3.415	117	-12 (-10)	281
884	10/20/41	1 mole 1S 200-250 + 1 mole higher fatty acids	0.935	cs. °E	585 76.9	200 26.3	105 13.85	20.2 2.89	3.097	88	-6 (+6)	220

Table 8G

Run No.	Date of Preparation	Ester from 1 Mole Trimethylolmethane and 3 Moles:	Specific Gravity, at 20°C	Viscosity			m	V.I.	Pour Point, °C	Flash Point, °C		
				Unit	20°C	38°C					50°C	99°C
602	3/24/41	H.S. acid + 5% higher fatty acids	0.965	cs. °F	49.0 6.50	20.9 2.97	13.0 2.13	3.56 1.268	4.213	48	-57	197
97	1/14/39	LS 140-250 + 12.5% higher fatty acids	0.954	cs. °F	73.2 9.65	29.8 4.05	—	4.99 1.392	3.727	107	-28	197
117	3/14/39	LS 140-250 + 15% higher fatty acids	0.957	cs. °F	74.4 9.81	30.2 4.09	—	4.94 1.388	3.772	101	-10	186
126	3/25/39	LS 140-250 + 18% higher fatty acids	0.949	cs. °F	70.2 9.26	28.8 3.92	—	4.76 1.372	3.799	98	-7	190+
111	3/6/39	LS 140-250 + 25% higher fatty acids	0.957	cs. °F	79.7 10.5	35.4 4.50	—	5.36 1.424	3.709	106	+2	194
48	10/27/38	1 part LS 140-250 1 part LS 200-250	0.968	cs. °F	92.3 12.15	33.1 4.45	—	4.90 1.384	3.937	74	-52	206
47	10/24/38	1 part LS 140-250 1.5 parts LS 200-250	0.966	cs. °F	114 15.01	39.27 5.24	—	5.42 1.429	3.924	72	-48	207
67	11/26/38	1 part LS 140-250 2 parts LS 200-250	0.958	cs. °F	121 15.93	41.7 5.55	—	5.64 1.448	3.095	74	-47	200
90	1/14/39	1 part LS 140-250 1.3 parts LS 200-250 + 7.5% higher fatty acids	0.953	cs. °F	96.5 12.70	35.8 4.93	—	5.62 1.446	3.731	101	-41	192

Table 8H

Run No.	Date of Preparation	Ester from 1 Mole Trimethylolmethane and 3 Moles:	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
424	6/5/40	2 parts IS 200-250 8 parts higher fatty acids	0.930	cs. 199 26.19	81.7 10.76	--	--	12.6 2.08	140	- 4 (+10)	309
457	9/4/40	1 part IS 200-250 9 parts higher fatty acids	0.932	cs. 257 53.8	89.6 11.8	--	--	12.5 2.07	132	+ 4 (+10)	294
456	9/24/40	0.5 parts IS 200-250 9.5 parts higher fatty acids	0.930	cs. 189.7 24.96	76.4 10.07	--	--	11.9 2.01	120	+ 4 (+10)	292
435	8/13/40	8 parts IS 200-250 2 parts stearic acid	0.942	cs. 133.7 17.50	49.5 6.56	--	--	6.75 1.543	97	-44	257
865	10/6/41	1/2 mole adipic acid 2 moles C ₆ -7 acid	1.053	cs. 865 113.8	245.4 32.3	127	16.72	20.8 2.96	108	-35	224

Table 9

Run No.	Date of Preparation	Ester from Tri-methylolpropene and:	Specific Gravity, at 20°C	Viscosity				m	V.I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
138	4/11/39	IS 140-250 + 15% higher fatty acids	0.959	cs.	75.25	30.33	—	4.6	70+	-90+	197
				°E	9.92	4.11	1.359				
172	5/15/39	IS 165-250 + 10% top cut of fatty acid C7-C11	0.958	cs.	85.2	32.5	—	4.9	93	-48	191
				°E	10.90	4.38	1.391				

Table 10

Run No.	Date of Preparation	Ester from Glycerol and:	Specific Gravity, at 20°C	Viscosity				m	V.I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
153	4/25/39	Top cut of fatty acids C ₅ -C ₆	0.985	cs. 16.7 °E 2.50	8.90 1.731	—	—	3.680	—	-76	197
151	4/25/39	1 part top cut of fatty acids C ₅ -C ₇ 1 part top cut of fatty acids C ₇ -C ₁₁	0.979	cs. 22.2 °E 3.12	11.5 1.972	—	—	3.708	139	-71	192
152	4/25/39	Top cut of fatty acids C ₉ -C ₁₁	0.941	cs. 52.7 °E 6.97	24.3 3.37	—	—	3.406	139	—	195
242	8/21/39	Stearic acid	—	—	—	—	—	—	—	—	222
217	7/6/39	Oil acids	0.923	cs. 90.0 °E 11.86	42.7 5.68	—	—	2.858	162	-16	290
2	9/8/37	LS C ₆	0.978	cs. 20.2 °E 2.89	9.66 1.80	—	—	3.862	—	—	187
3	5/27/38	LS C ₇	0.962	cs. 22.4 °E 3.15	10.8 1.905	—	—	3.811	113	—	202
4	5/30/38	LS C ₈	0.956	cs. 41.9 °E 5.58	17.8 2.62	—	—	3.881	97	—	209
5	5/30/38	LS C ₉	0.954	cs. 48.6 °E 6.44	20.8 2.96	—	—	4.056	96	—	215
270	10/4/39	LS 140-250	0.970	cs. 32.1 °E 4.33	14.7 2.29	—	—	3.899	96	-57	199
136	4/4/39	LS 140-250 + 15% higher fatty acids	0.965	cs. 48.66 °E 6.45	21.2 3.01	—	—	3.811	112	-12	195
	8/28/37	LS 200-250	0.954	cs. 94.4 °E 12.44	34.0 4.57	—	—	3.962	71	-60	207

Table 10A

Run No.	Date of Preparation	Ester from Glycerol and:	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C	
				Unit	20°C	38°C	50°C					99°C
214		IS 200-250 + 10% higher fatty acids	0.952	cs. °E	104.5 13.75	38.5 5.14	— —	5.31 1.420	3.948	69	-33	200
81	1/4/59	1 part IS 140-250 1.5 parts IS 200-250	0.961	cs. °E	59.8 7.91	24.3 3.37	— —	4.22 1.326	3.863	93	-59	203
56	11/11/38	1 part IS 140-250 1.5 parts IS 200-250	0.967	cs. °E	62.53 8.27	24.86 3.44	— —	4.62 1.35	3.642	85	-53	206

Table 11

Run No.	Date of Preparation	Ester from 1 Mole Pentaerythritol and 4 Moles:	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
462	10/8/40	Higher fatty acids	--	--	198.2	--	20.7	3.045	121	+12	250
					26.08	--	2.95				
482	7/17/40	15 C ₆ -C ₇	0.989	105.2	37.5	--	5.45	3.842	86	-52	235
				13.86	5.02	--	1.432				
573	2/14/41	3 Moles 15 C ₆ -C ₇	1.000	187.5	61.1	33.5	6.61	3.033	46	-43	228
				24.67	8.07	4.51	1.531				
597	3/16/41	2 Moles 15 C ₆ -C ₇	1.02	432.7	116.4	59.0	9.22	3.063	30	-35	220
				66.9	15.32	7.80	1.760				
459	9/4/40	15 C ₆ -C ₇ + 10% higher fatty acids	0.986	137.2	51.3	--	1.541	3.754	89	-38	232
				18.05	6.79	--	6.77				
427	7/17/40	15 200-250	0.961	453	117.2	--	10.46	3.784	70	-31	284
				59.6	15.43	--	1.874				
439	7/7/40	15 200-250 + 7.5% higher fatty acids	0.958	349.3	111	--	10.7	3.674	85	-42	285
				46.0	14.61	--	1.896				
458	9/4/40	15 200-250 + 15% higher fatty acids	0.971	376	113.2	--	10.4	3.761	73	-34	265
				49.5	14.9	--	1.867				

Table 12

Run No.	Date of Preparation	Ester of Adipic Acid and:	Specific Gravity, at 20°C	Viscosity				m	V. I.	Four Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
421	7/1/40	Methanol	1.062	cs. °E	3.08 1.224	2.14 1.133	1.55 1.070	0.851	—	+ 5	139
422	7/1/40	Ethanol	1.009	cs. °E	3.41 1.254	2.31 1.151	1.858 1.104	0.990	—	-22 (-18)	138
335	1/12/40	n-Butanol	0.961	cs. °E	5.71 1.454	3.68 1.278	2.99 1.216	1.49 1.063	2.936	-25	170
423	6/2/40	n-Octanol	0.919	cs. °E	14.8 2.30	8.75 1.718	6.23 1.503	2.35 1.203	2.748	+ 4 (+10)	215
370	4/5/40	i-Butanol	0.952	cs. °E	6.50 1.521	4.08 1.314	—	1.56 1.071	3.424	0	163
362	2/15/40	C ₅ Alcohol synth.	0.948	cs. °E	7.97 1.649	4.76 1.372	—	1.75 1.092	3.333	—	175
364	2/15/40	i-C ₆ Alcohol	0.935	cs. °E	8.81 1.723	5.675 1.451	—	1.98 1.117	3.365	—	189
365	2/15/40	i-C ₈ Alcohol	0.925	cs. °E	14.3 2.25	7.83 1.657	5.85 1.456	2.25 1.146	3.244	—	215
315	11/13/39	IA 140-165	0.937	cs. °E	12.0 2.02	6.90 1.556	—	2.11 1.130	3.617	—	185
719	7/16/41	IA 140-180	0.934	cs. °E	14.5 2.27	7.86 1.639	5.76 1.458	2.24 1.144	3.704	—	190
455	9/4/40	IA 140-200	0.933	cs. °E	15.4 2.36	8.39 1.686	—	2.46 1.165	3.953	—	186
369	2/28/40	IA 140-250	0.933	cs. °E	17.6 2.60	8.92 1.733	—	2.59 1.178	3.613	187	190

Table 12A

Run No.	Date of Preparation	Ester from Adipic Acid and:	Specific Gravity, at 20°C	Viscosity				m	V.I.	Four Point, °C	Flash Point, °C	
				Unit	20°C	38°C	50°C					99°C
467	9/24/40	IA 165-200	0.932	cs. °E	20.1 2.88	10.03 1.834	— —	2.70 1.189	3.592	163	-70	200
290	10/11/39	IA 165-250	0.930	cs. °E	20.9 2.97	11.44 1.956	— —	2.95 1.210	3.591	160	-69	167
325	11/13/39	IA 180-250	0.930	cs. °E	32.73 4.41	16.4 2.47	10.85 1.910	3.165 1.276	3.601	143	-69	178
414	6/25/40	IA 190-250	0.932	cs. °E	38.4 5.13	18.0 2.64	12.0 2.02	5.91 1.239	3.564	145	-63	190
498	10/23/40	IA 200-250	0.930	cs. °E	49.0 5.50	21.6 3.05	14.1 2.23	4.33 1.335	3.588	137	-64	200
567	2/10/40	HOC-(CH ₂) ₄ -COOR R=n-C ₈ Alcohol i-C ₈ Alcohol	0.922	cs. °E	15.1 2.33	8.50 1.636	5.20 1.436	2.52 1.171	3.460	191	-24	207
546	1/10/40	IA 165-260	0.919	cs. °E	17.3 2.57	9.39 1.775	— —	2.66 1.185	3.491	175	-29	208

Table 13

Run No.	Date of Preparation	Mixed Esters of the Semi-Esters (HE) of HOOC(CH ₂) ₄ CO ₂ R	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
539	1/5/41	R = IA C ₆ -C ₇ 1,4-Butanediol + 2 Moles HE	1.005	cs. 90.0 °E 11.86	cs. 39.67 °E 5.29	— —	7.16 1.58	3.224	145	-3	200
540	1/5/41	Pentaglycol + 2 Moles HE ✓	1.002	cs. 138 °E 18.16	cs. 54.4 °E 7.19	— —	8.48 1.594	3.284	132	-42	220
721	7/21/41	R = IA 140-180 Glycol + 2 Moles HE	0.992	cs. 43.53 °E 5.79	cs. 20.1 °E 2.88	13.3 2.15	4.50 1.333	3.482	150	-62	218
720	7/21/41	1,4-Butanediol + 2 Moles HE	0.993	cs. 57.7 °E 7.63	cs. 26.8 °E 3.57	17.2 2.56	5.375 1.425	3.350	150	-33	216
836	9/12/41	Adipol + 2 Moles HE	0.983	cs. 64.2 °E 8.47	cs. 29.53 °E 4.00	19.8 2.85	6.14 1.490	3.159	162	-19 (-5)	205
837	9/12/41	Methyladipol + 2 Moles HE	0.995	cs. 87.5 °E 11.5	cs. 40.2 °E 5.56	25.3 3.49	7.225 1.584	3.230	144	-60	218
778	8/19/41	Dimethylolpropane + 2 Moles HE	0.982	cs. 64.0 °E 8.45	cs. 27.9 °E 3.81	17.8 2.62	5.30 1.419	3.455	139	-56	205
724	7/21/41	Dimethylolpentane + 2 Moles HE	0.989	cs. 93.4 °E 12.3	cs. 40.33 °E 5.38	25.52 3.52	6.94 1.559	3.334	137	-53	215

Table 13A (Continued)

Run No.	Date of Preparation	Mixed Esters of Adipic Acid $\text{HOOC}(\text{CH}_2)_4\text{CO}_2\text{OR}$ with:	Specific Gravity, at 20°C	Viscosity				m	V.I.	Pour Point, °C	Flash Point, °C	
				Unit	20°C	38°C	50°C					99°C
		R = 1A 180-250										
850	10/2/41	Adipol + 2 Moles HE	0.975	cs. °E	177.5 23.36	70.2 9.26	40.73 5.43	9.50 1.785	3.368	121	-37	231
623	4/14/41	Pentaglycol + 2 Moles HE	0.980	cs. °E	146.7 19.32	55.1 7.29	33.6 4.39	7.975 1.649	3.442	120	-51	184
682	6/10/41	P5 + 3 Moles HE	0.990	cs. °E	333 43.8	108.8 14.32	62.5 8.25	13.1 2.13	3.233	121	-45	220
708	7/8/41	P3 + 2 Moles HE	0.985	cs. °E	368.7 48.5	121.9 16.04	67.5 8.91	13.6 2.18	3.291	114	-43	200
707	7/8/41	P3 + 1 Mole HE	1.010	cs. °E	1164 155.1	309.3 40.7	159.5 20.99	23.6 3.29	3.270	103	-36	186

Table 14

Run No.	Date of Preparation	Esters of α - or β -Methyladipic Acid and:	Specific Gravity, at 20°C	Viscosity				V.I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C			
		<u>α-Methyladipic Acid</u>								
443	8/12/40	n-C ₈ Alcohol	0.927	cs. °E 16.8 2.51	9.33 1.770	6.66 1.535	2.66 1.185	183	-32 (-15)	208
538	4/28/41	n-C ₁₂ Alcohol	0.913	cs. °E 36.13 4.84	17.3 2.57	12.1 2.03	4.28 1.331	179	+16	231
816	9/13/41	IA 140-180	0.944	cs. °E 16.1 2.44	8.65 1.709	6.20 1.496	2.35 1.155	—	<-72	181
664	5/22/41	IA 140-200	0.940	cs. °E 16.5 2.48	8.65 1.709	6.14 1.490	2.36 1.156	—	<-72	180
735	7/29/41	IA 180-250	0.933	cs. °E 49.2 6.52	20.9 2.97	13.4 2.16	4.07 1.513	120	-60	196

Table 15

Run No.	Date of Preparation	Ester from β -Methyladipic Acid	Specific Gravity, at 20°C	Viscosity				V.I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C			
622	4/10/41	n-C ₈ Alcohol	0.920	cs. °E 15.0 2.43	9.22 1.760	6.57 1.537	2.90 1.207	228	-36	227
640	4/28/41	n-C ₁₂ Alcohol	0.898	cs. °E 55.9 4.81	18.6 2.71	13.2 2.14	4.71 1.368	185	+10	—
714	7/9/41	LA 140-200	0.986	cs. °E 17.0 2.53	8.91 1.732	6.50 1.521	2.51 1.170	167	<-72	185
713	7/9/41	LA 180-250	0.913	cs. °E 49.6 6.57	21.2 3.01	13.6 2.18	4.16 1.321	125	-59	150+

Table 16

Run No.	Date of Preparation	Mixed Esters from α - or β -Methyladipic Acid $\text{HOOC}(\text{CH}_2)_n\text{CH}_2\text{CH}_2\text{COOR}$	Specific Gravity, at 20°C	Viscosity				m	V.I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
576	2/25/41	<u>R = i-C₈ Alcohol</u> n-C ₈ Alcohol	0.924	cs. °E	7.84 1.635	2.39 1.159	3.446	--	<-70 (-48)	276	
649	5/9/41	n-C ₁₂ Alcohol	0.907	cs. °E	28.8 3.92	15.0 2.32	10.69 1.895	3.340	178	-20 (-10)	146
819	9/8/41	n-C ₁₈ Alcohol	0.906	cs. °E	-- --	21.2 3.01	14.3 2.28	3.151	175	+19	241
718	7/15/41	<u>R = n-C₁₂ Alcohol</u> IA 180-250	0.908	cs. °E	40.5 5.36	19.85 2.85	13.3 2.15	3.331	164	-12 (-10)	--
650	5/12/41	Pentaglycol	0.940	cs. °E	58.1 7.68	28.4 3.87	18.8 2.73	3.397	154	+8	215

Table 17

Run No.	Date of Preparation	Various Esters	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C	
				Unit	20°C	38°C	50°C					99°C
591	3/12/41	HS Alcohol + Meth- thentic Acid	0.928	cs. °E	20.3 2.90	9.76 1.809	7.00 1.564	2.56 1.175	3.714	139	-61 (-43)	176
333	11/19/39	LA 140-165 + Phthalic Acid	1.007	cs. °E	60.4 7.98	27.6 3.77	—	3.92 1.300	4.293	6	-55	197
384	3/21/40	i-C ₈ Alcohol + Oil Acids	0.857	cs. °E	15.8 2.41	9.03 1.745	—	2.75 1.193	3.295	217	-67 (-18)	222
506	3/26/41	i-C ₈ Alcohol + Sebacic Acid	0.912	cs. °E	23.2 3.24	12.2 2.04	8.70 1.713	3.30 1.244	3.456	189	< -72 (-42)	235
93	1/16/39	i-C ₈ Alcohol + Phthalic Acid	0.990	cs. °E	121 15.93	33.8 5.18	—	5.04 1.396	4.101	43	-48	178
429	7/17/40	LA 165-250 + Phthalic Acid	0.988	cs. °E	354.7 44.0	77.7 10.25	—	7.075 1.571	4.180	16	-37	195
453	8/31/40	LA 200-250 + Mono- chloroacetic Acid	0.958	cs. °E	27.0 3.70	12.0 2.02	—	2.86 1.204	3.771	123	-65	175
94	1/16/39	LA 200-250 + Phthalic Acid	0.977	cs. °E	351 46.2	89.2 11.75	—	7.34 1.594	4.265	3	—	—
324	11/10/39	Cyclohexanol + IS 200- 250	0.917	cs. °E	7.65 1.621	5.30 1.419	—	1.54 1.06	4.215	—	< -78	150
851	9/26/41	2,2,4-Trimethyl Pentane-1,3 + n-C ₈ Acid	0.910	cs. °E	16.5 2.48	8.95 1.736	6.45 1.517	2.46 1.165	3.663	—	< -72	184

Table 17A

Run No.	Date of Preparation	Various Esters	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	33°C	50°C				
390	4/9/40	n-Butanol + Mono-chloroacetic Acid	—	cs. °E 1.71 1.088	1.24 1.082	—	—	—	-27	94	
275	10/11/39	n-Butanol + n-C ₆ Acid	—	cs. °E 1.68 1.084	1.28 1.037	—	—	—	<-72	88	
274	10/11/39	n-Butanol + IS C ₅	—	cs. °E 1.58 1.073	1.18 1.024	—	—	—	<-72	78	
331	11/18/39	n-Butanol + IS C ₆	—	cs. °E 1.64 1.08	1.25 1.033	—	—	—	<-72	77	
230	8/4/39	Isobutyl Phthalate	—	cs. °E 37.87	15.75	—	—	4.356	-56	163	
				cs. °E 5.06	2.40	—	—	—	—	—	—
452	8/30/39	C ₆ Alcohol + 1,2,3,4-Butane Tetracarboxylic Acid	1.044	cs. °E —	57.9	—	—	3.398	122	-31	—
				cs. °E 8.00	4.82	—	—	—	—	—	—
450	8/25/39	C ₆ Alcohol + 2 Moles Ethylene Oxide + i-C ₆ Acid	0.942	cs. °E 1.551	1.378	—	—	3.325	—	<-78	168
				cs. °E 20.7	11.6	—	—	—	—	—	—
438	8/5/40	HS Alcohol + 8 Moles Ethylene Oxide + Adipic Acid	1.053	cs. °E 2.95	1.981	—	—	3.224	205	-45 (-35)	207
				cs. °E 130.8	63.1	—	—	—	—	—	—
				17.2	8.53	—	—	2.696	-8 (-5)	265	

—Forward—

Table 17A (Continued)

Run No.	Date of Preparation	Various Esters	Specific Gravity, at 20°C	Viscosity				m	V. I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	39°C	50°C				
485	10/8/40	HS Alcohol + 4 Moles Ethylene Oxide + Methyladipic Acid	1.025	cs.	74.3	34.0	--	6.88	158	-44 (-38)	245
				°E	9.80	4.57	--	1.554			
484	10/8/40	HS Alcohol + 6 Moles Ethylene Oxide + Methyladipic Acid	---	cs.	82.4	38.5	--	7.76	159	-44 (-34)	252
				°E	10.92	5.14	--	1.631			
430	7/17/40	HS Alcohol + HS Acid	0.862	cs.	3.41	2.28	1.85	1.02	---	<-72	121
				°E	1.254	1.148	1.103	1.003			

Table 17B

Run No.	Date of Preparation	Various Esters	Specific Gravity, at 20°C	Viscosity				m	V.I.	Pour Point, °C	Flash Point, °C
				Unit	20°C	38°C	50°C				
293	11/6/39	C ₁₄ Glycol + IS C ₆ -C ₇	0.883	cs.	17.15	8.45	--	3.990	--	-65	167
				°E	2.55	1.691	--	1.137			
447	/17/40	Hexanetriol + IS C ₆ -C ₇	0.860	cs.	40.8	17.0	--	4.051	62	-57	192
				°E	5.44	2.53	--	1.238			
446	8/19/40	Hexanetriol + IS 200-250	0.953	cs.	67.6	37.6	--	2.574	174	-42	230
				°E	8.92	5.03	--	1.765			
140	4/13/39	Laurintriol + IS 140E	--	cs.	88.75	34.4	--	3.804	93	-50	200
				°E	11.69	4.62	--	1.415			